Qualification Development of AlSi10Mg for Robotic Spaceflight

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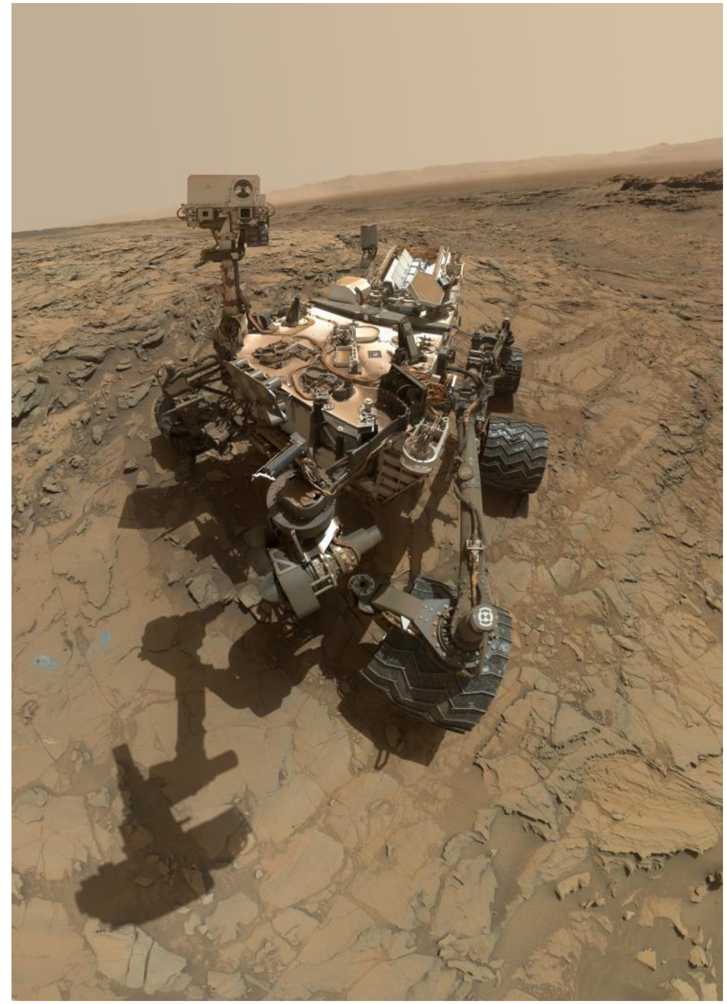
Agenda

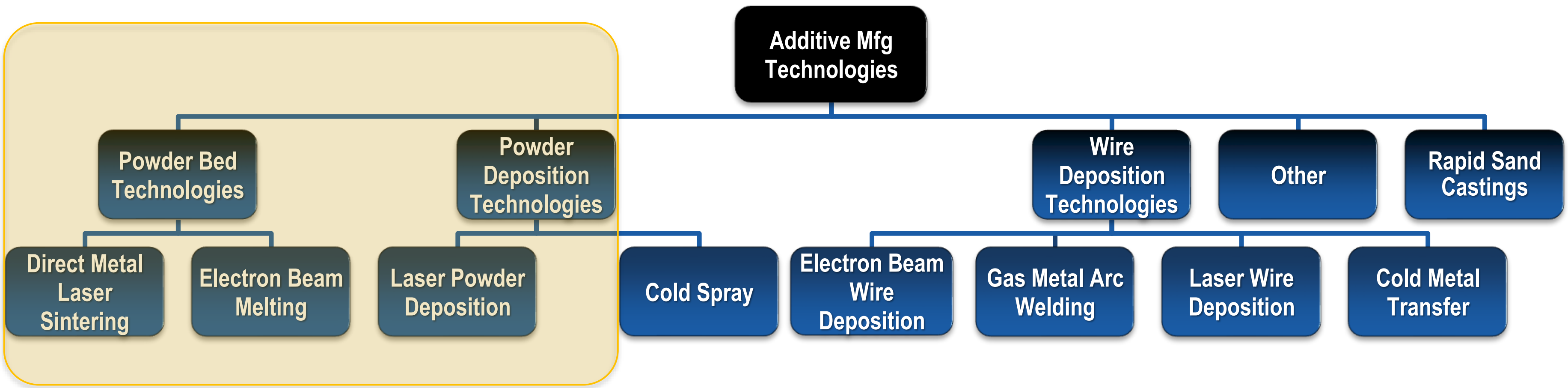
1. Applications
2. JPL Qualification Methodology
3. Flight & Development Insertion Opportunities
   - Mars Science Mission 2020
   - PIXL
4. Acknowledgements

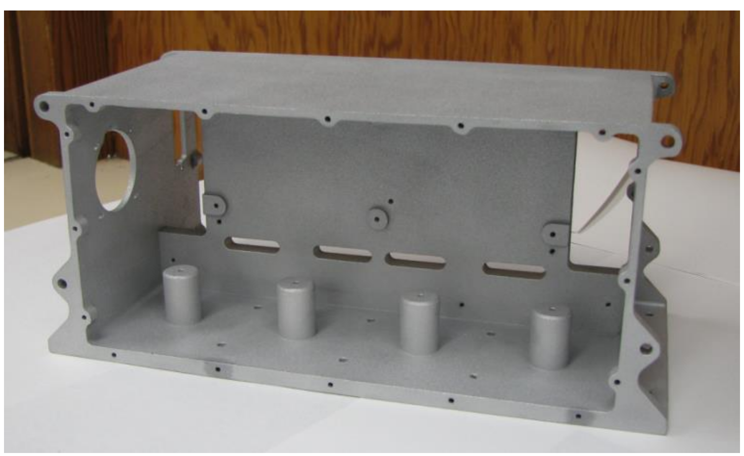


Mars Science Laboratory (Curiosity) / Mars 2020 (Image JPL/NASA)

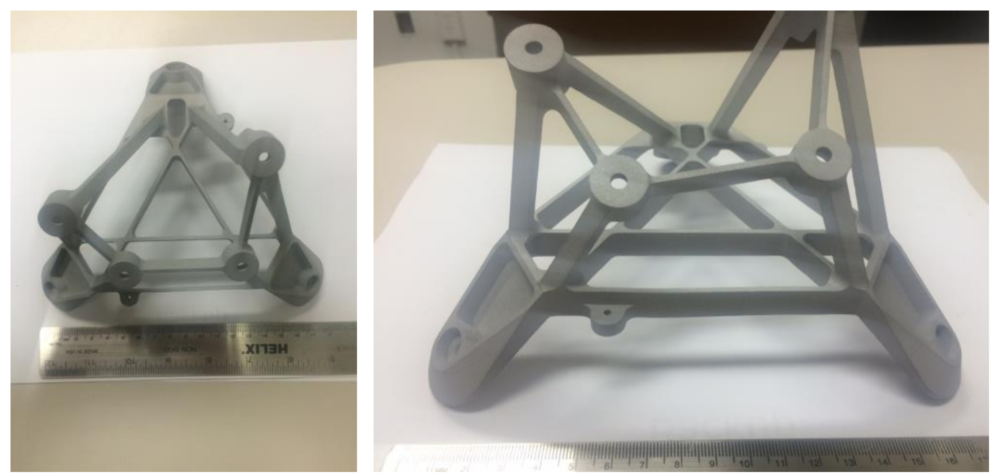
Additive Manufacturing Technologies Overview

Additive Manufacturing at JPL, briefing





Direct Metal Laser Sintering (DMLS)
SEP Electronics Chassis (AlSi10Mg)



Direct Metal Laser Sintering (DMLS)
MAHLI Bracket (AlSi10Mg)

Additive Manufacturing Materials, Metallics

Aluminum and titanium alloys comprise 85% of flight structural components

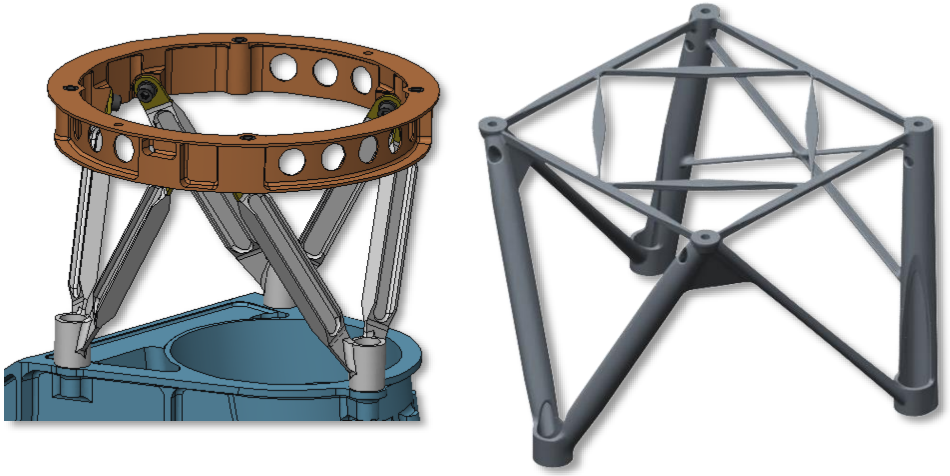
- Ti-6Al-4V produced via EBM (Arcam) process is baseline for flight use due to robust database
- JPL primary aluminum alloys are Al 2024, 6061, 7050, 7075
  - Current AM offering, AlSi10Mg (SAE 4032), doesn't correspond to existing alloy classes *used by JPL*
  - Challenge to integration due to lack of familiarity

Challenges

- Manned spaceflight and Class A missions require A-basis for primary structure, B-basis for secondary structure
  - Database for AlSi10Mg is not publicly available and is expensive for limited part set
- JPL's missions are generally single build, so total cost cannot be amortized over a single part or part-family

Qualification Methodology (Ti-6Al-4V)

- America Makes
  - B-Basis allowables effort current on-going to qualify Arcam electron beam melting machines (EBM)
  - Testing is a partnership between CalRAM (Camarillo, CA) and Northrop Grumman (El Segundo, CA)
  - ~ 1300 samples fabricated
  - Testing is complete
- Additional testing
  - Test matrix is designed for generic properties; doesn't cover all of JPL's needs
  - Augmenting test matrix with specimens from CalRAM and testing JPL-specific conditions (e.g. – 100 ^{o}C fatigue/tension behaviors)
  - High-cycle fatigue, fatigue crack growth and fracture toughness
  - Data required to support manned (e.g. International Space Station) missions

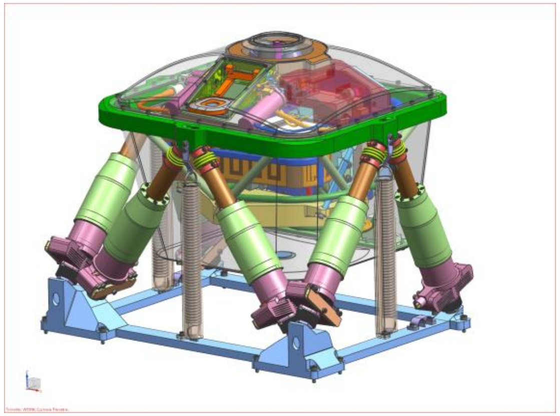


Mars Science Laboratory UHF Antenna Assembly

- Initial state (above left): 4-piece assembly with 6 bolted joints
- Final state (above right): 1-piece assembly
- 19% reduction in mass, as well as part count reduction

Qualification Methodology (AlSi10Mg)

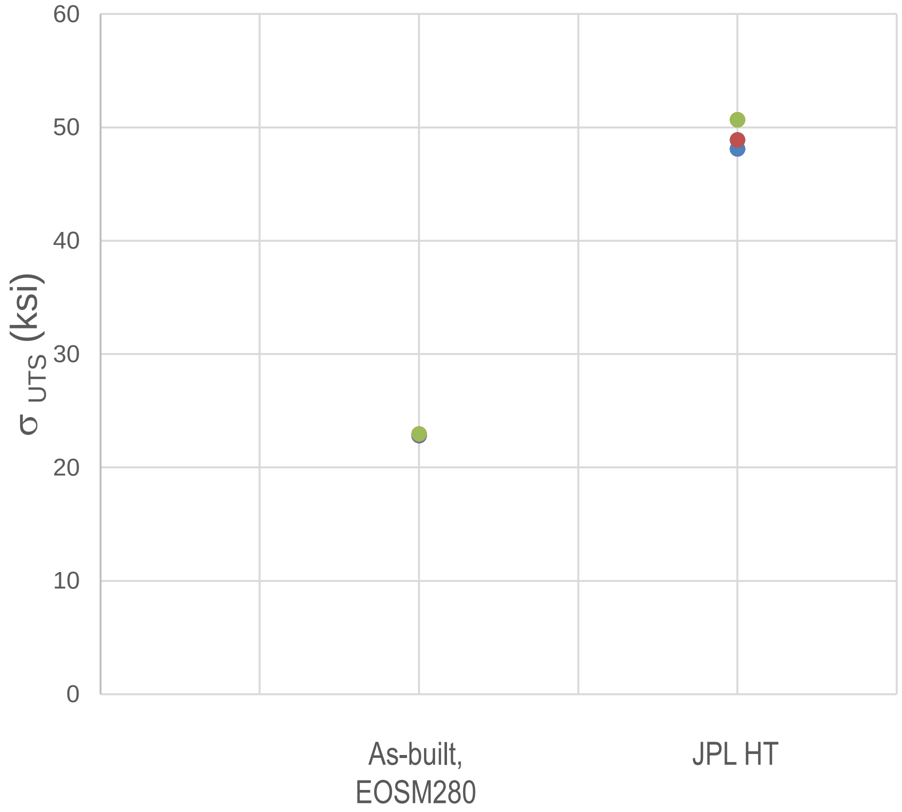
- Identification of insertion opportunities
  - Baseline properties determined through focused testing over a variety of temperatures (critical to JPL applications)
  - Capability determination of thermophysical properties
  - Understanding limited design space for non-traditional alloy
- Additional required efforts
  - Supplier variability
  - Aging
- Proof testing of components
  - Requires detailed understanding of actual loads and conditions
  - Must ensure testing accurately addresses concerns



Planetary Instrument for X-ray Lithochemistry (PIXL), Mars 2020 (Image JPL/NASA)

Element	Weight %
Al	Balance
Si	9.0-11.0
Mg	0.2-0.45
Fe	$\leq$ 0.55
Mn	$\leq$ 0.45
Ti	$\leq$ 0.15
Zn	$\leq$ 0.1
Cu, Ni, Pb, Sn	$\leq$ 0.05

Heat treatment effects



Standardized heat treatment
6 hrs at 538 °C (Ar)
Quench (H_2O) to 25 °C
158 °C, 2 – 4 hrs

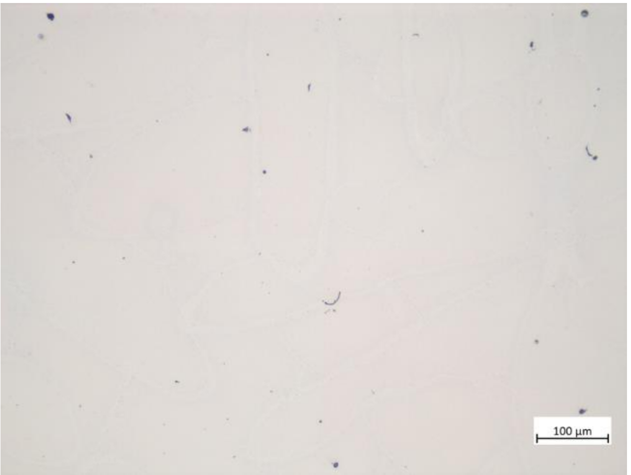
Elongation
As-HIP'ped: 30% ± 2.3%
Heat treated: 15% ± 1.4%

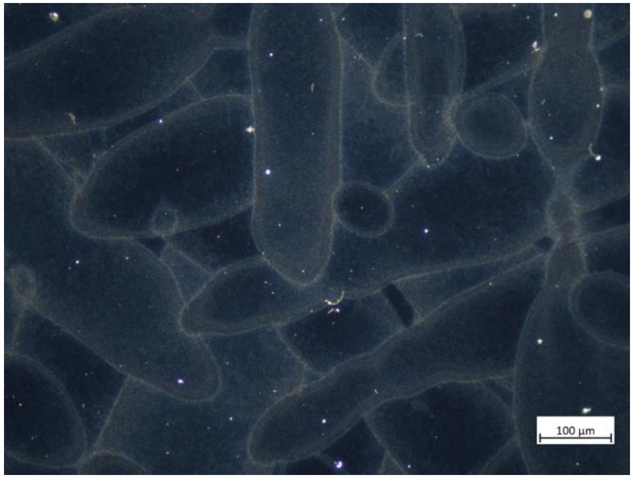
10 data points per condition

Instron 1331 #395182
Strain-controlled, 0.005 in/in/min
ASTM E8

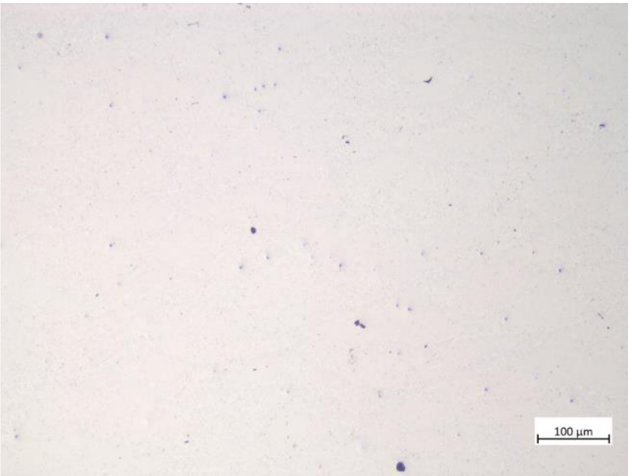
Alexopoulos and Pantelakis, *Materials & Design*, **25** (2004) 419-430.
Rometsch and Schaffer, *Materials Science & Engineering A*, **A325** (2002) 424-434.

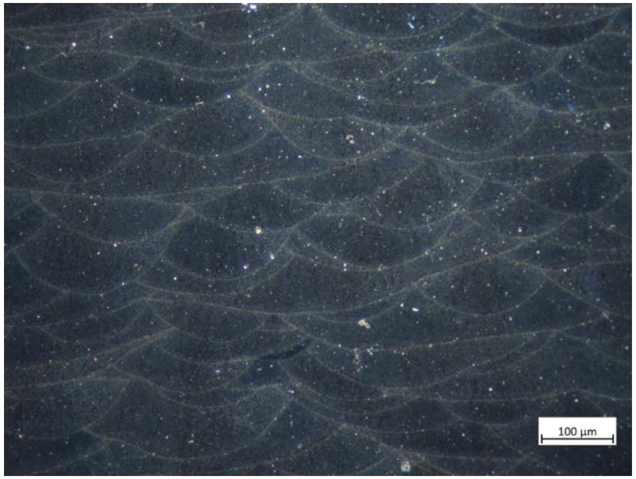
As-built microstructures





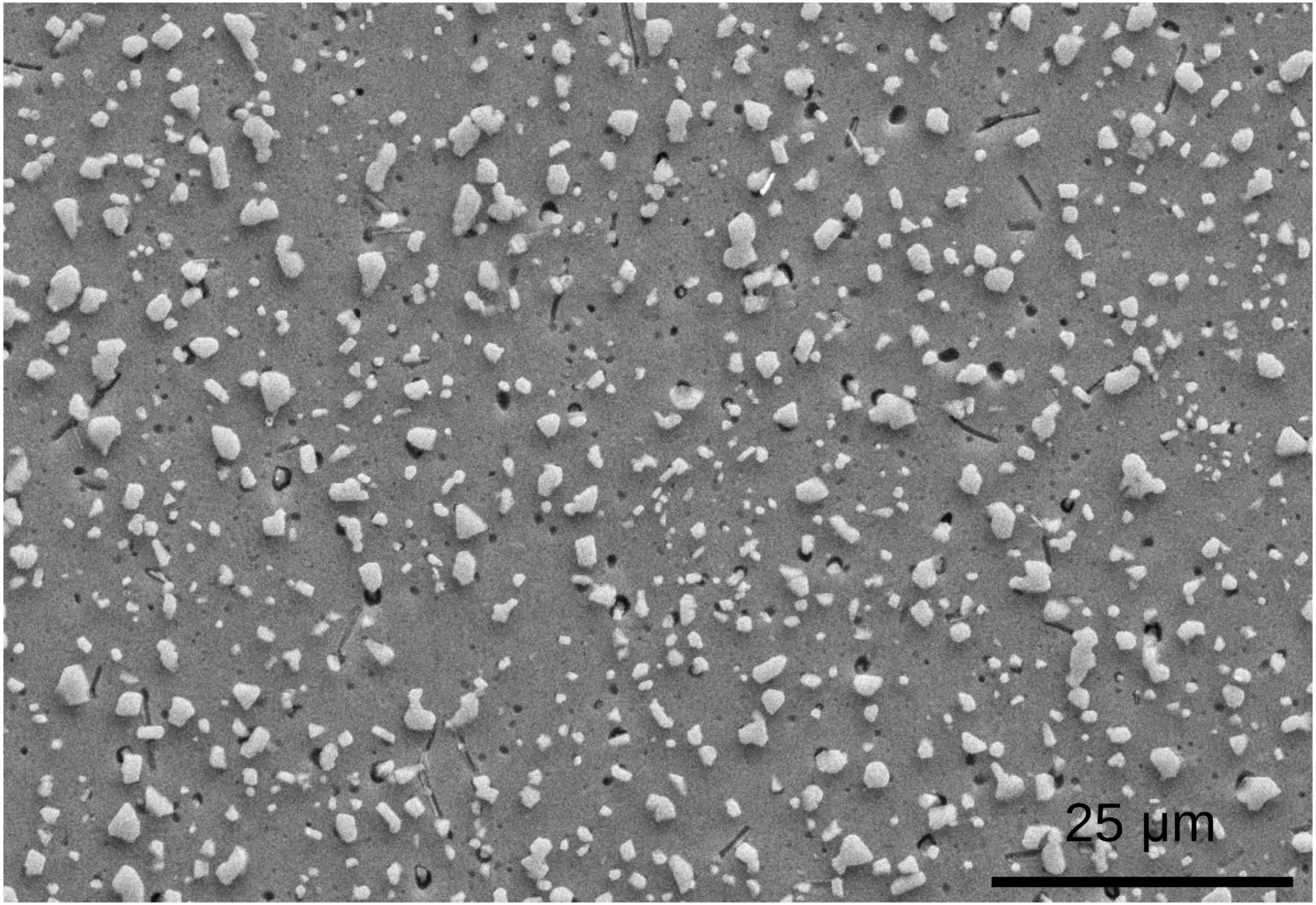
As-built, unetched, longitudinal (build) orientation; left: bright-field, right: dark-field





As-built, unetched, transverse orientation; left: bright-field, right: dark-field

Heat treatment microstructure



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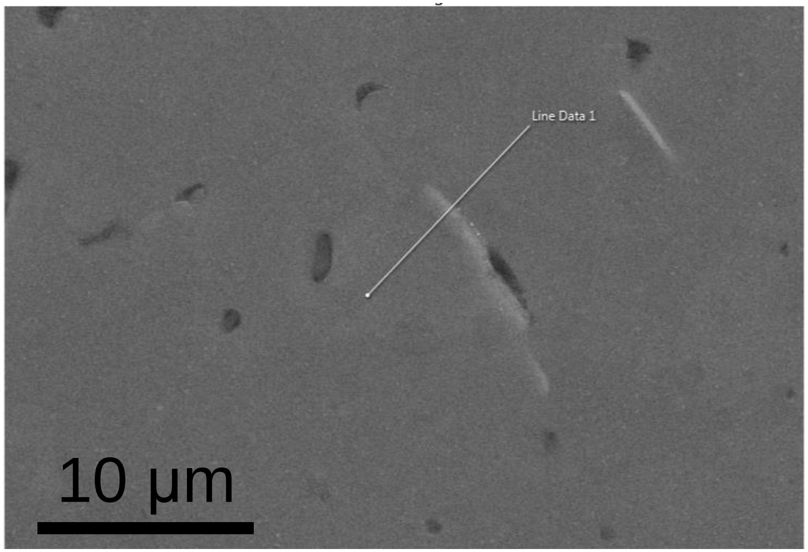
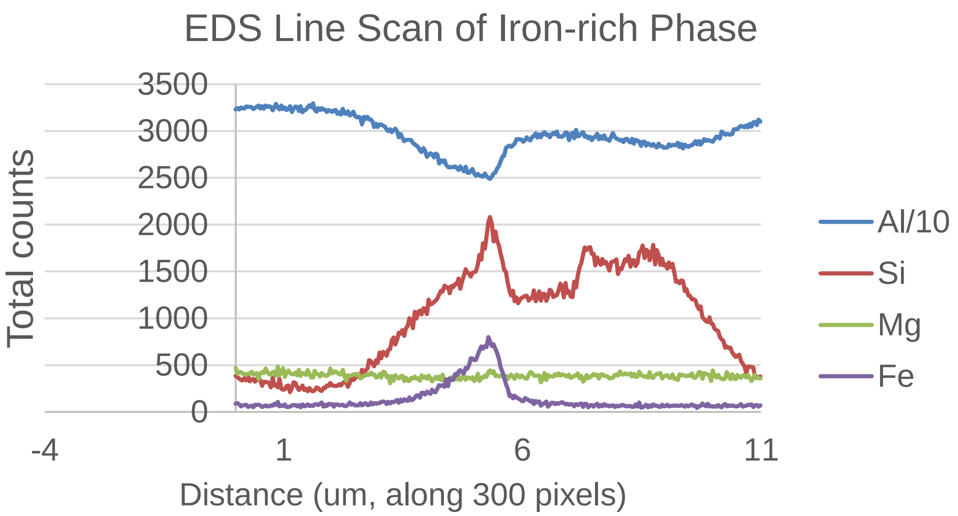
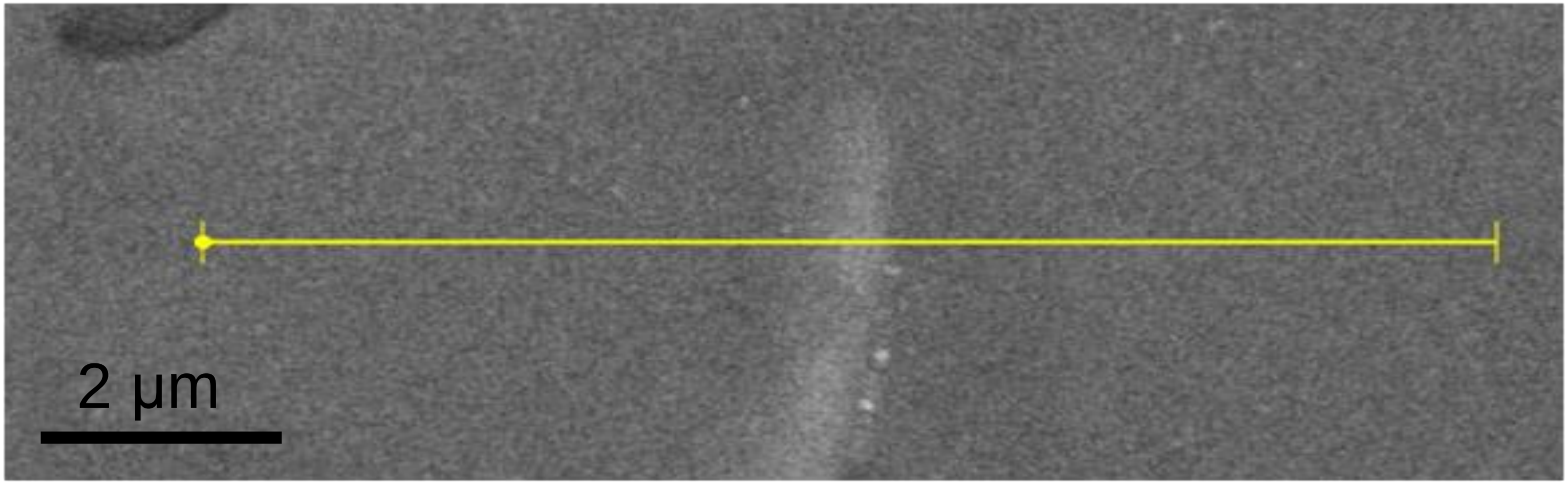
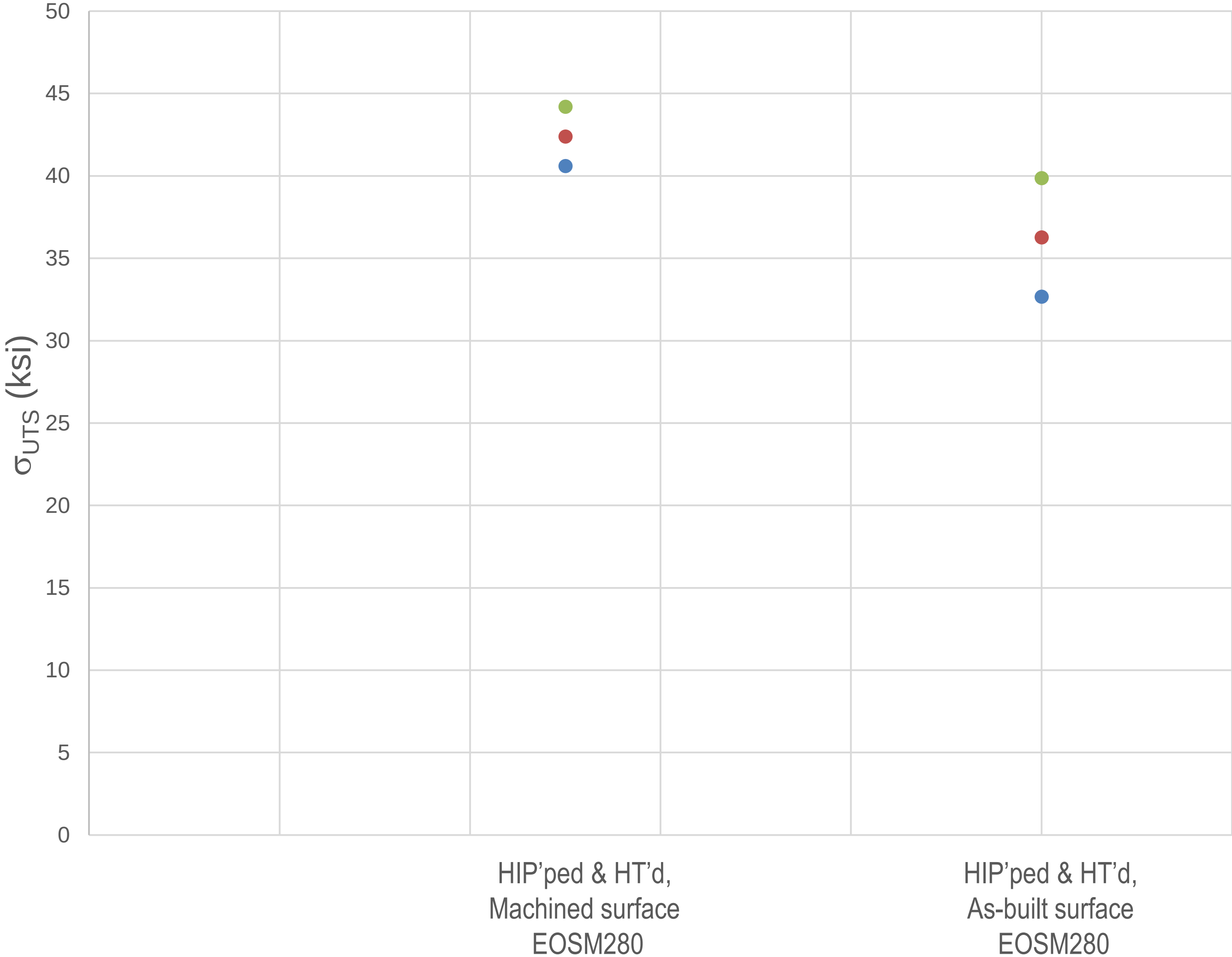




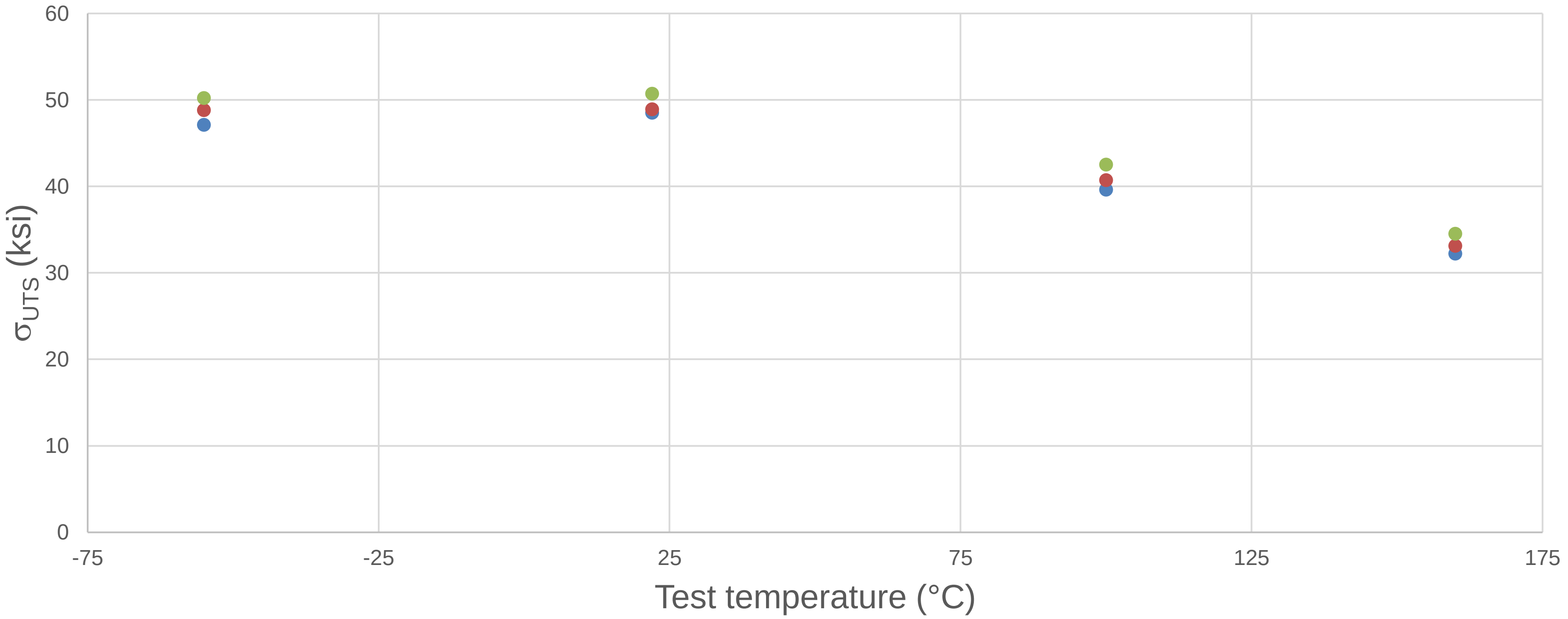


Surface finish effects



Instron 1331 #395182
Strain-controlled, 0.005 in/in/min
ASTM E8

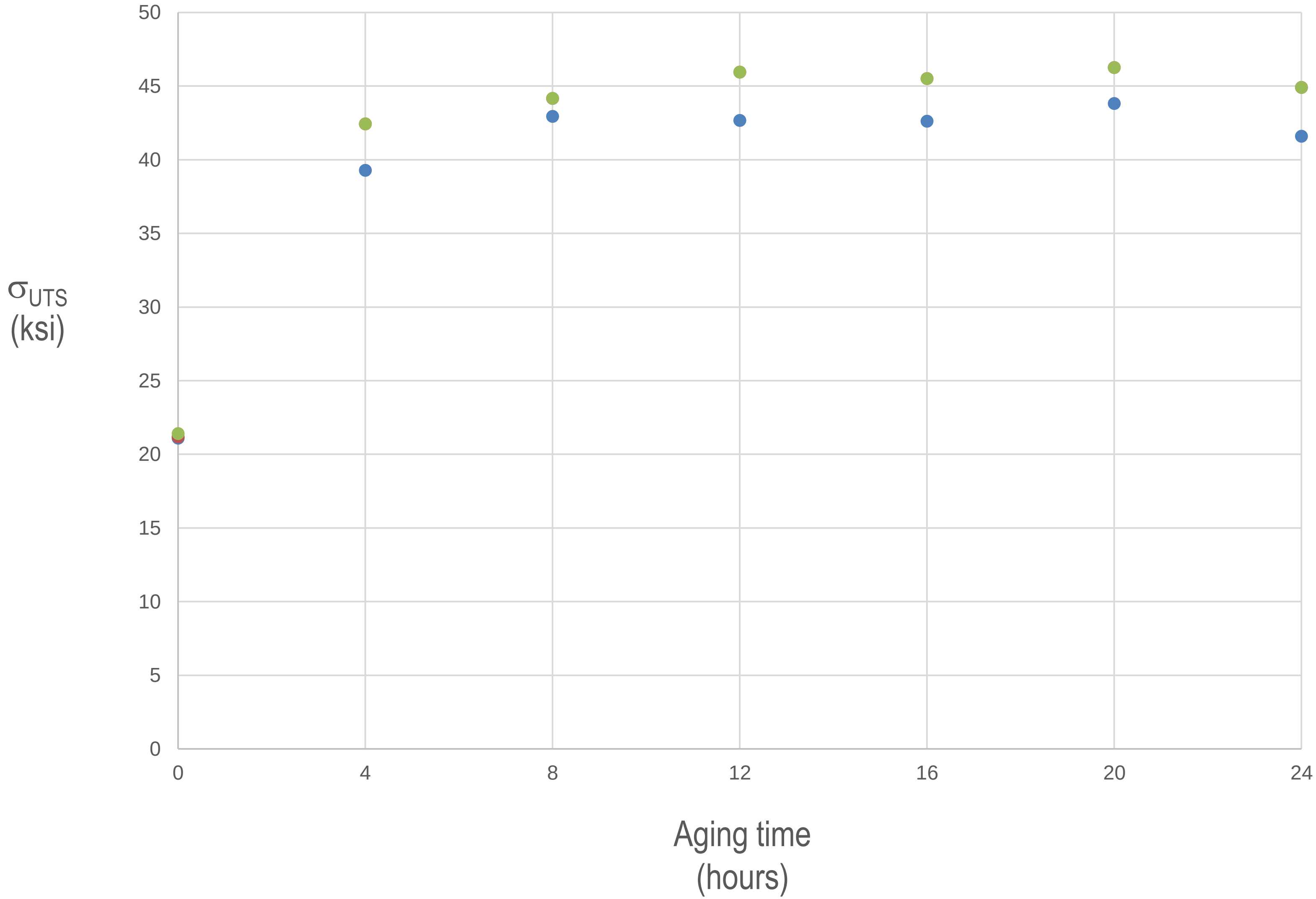
Tensile behavior of AlSi10Mg



Testing performed with JPL standard heat treatment
Bemco thermal control chamber

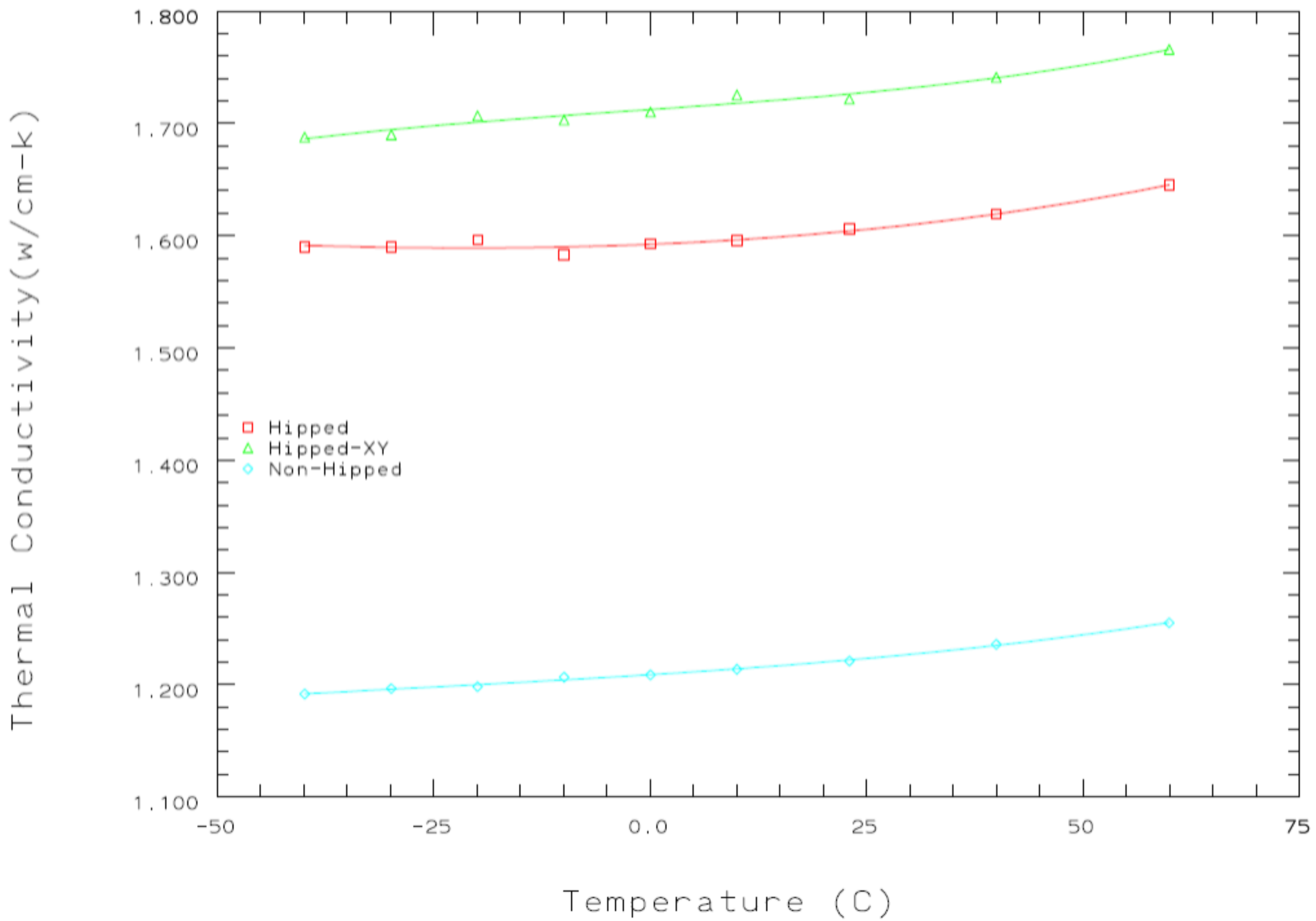
Instron 1331 #395182
Strain-controlled, 0.005 in/in/min
ASTM E8

Aging Behavior

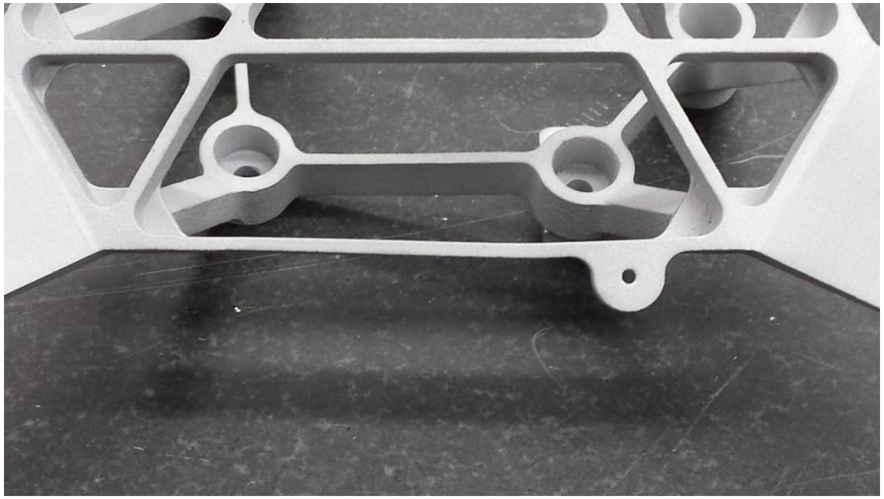


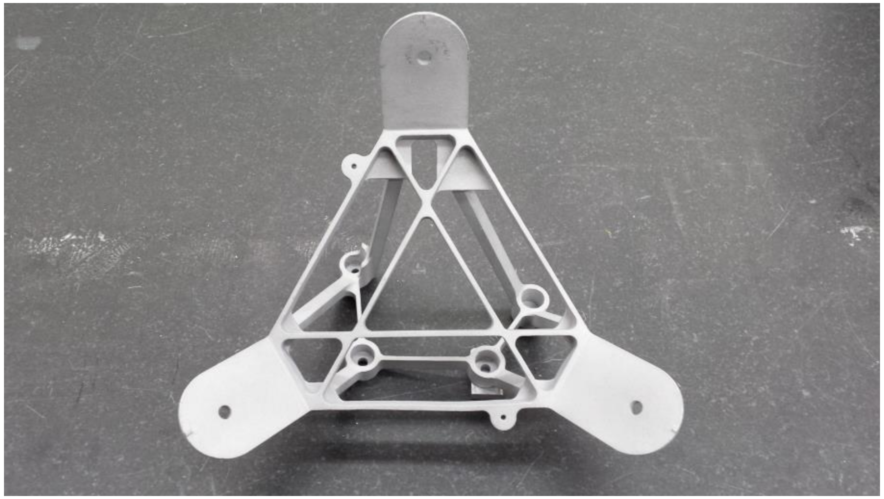
Instron 1331 #395182
Strain-controlled, 0.005 in/in/min
ASTM E8

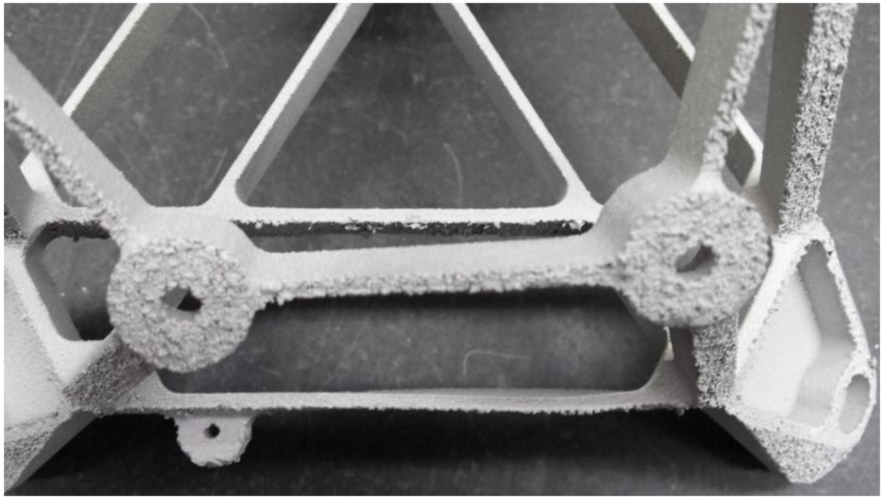
Additively Manufactured Aluminum Insertion (cont.)



Vendor Comparison



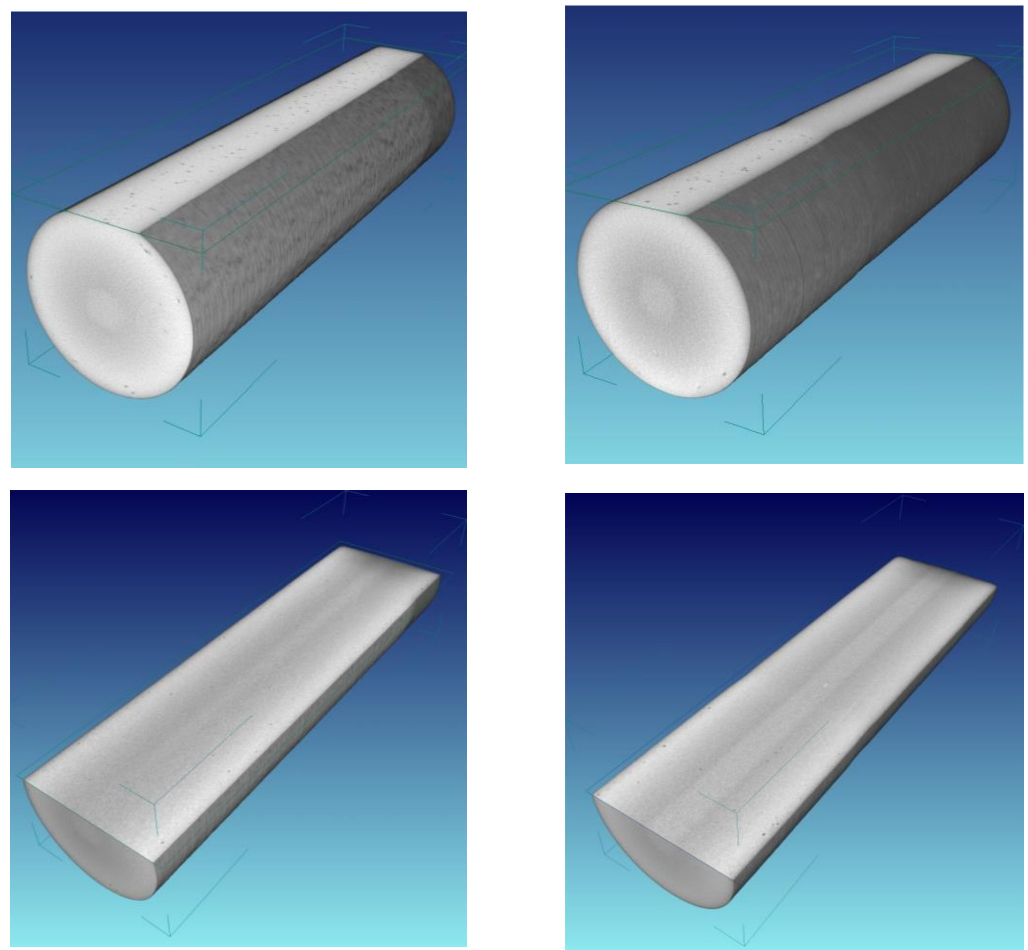




Non-destructive Evaluation (NDE)

1. CT inspection has revealed unacceptable levels of porosity in as-built parts (top and bottom figures, left)
2. Also viable to determine that partially effective HIP'ping processes do not completely eliminate porosity on the order of 50 µm (top and bottom figures, right)

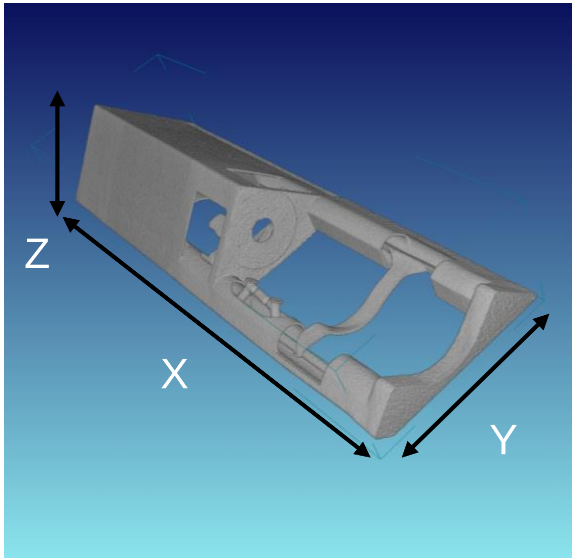
Sample geometry is 2.54 cm Ø x 15 cm length

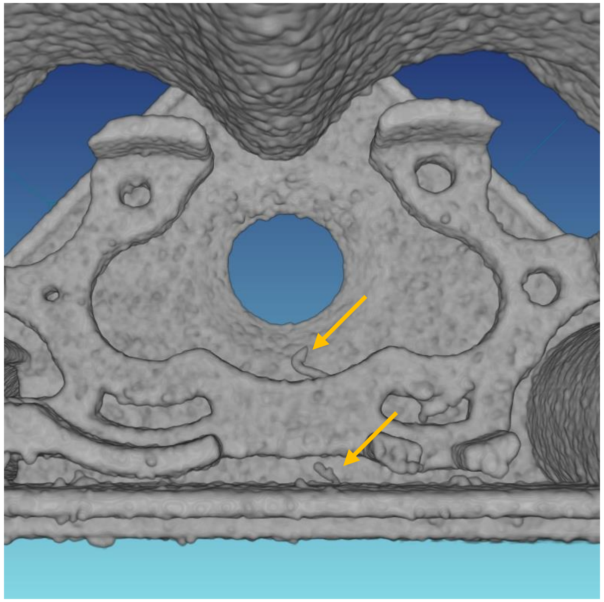


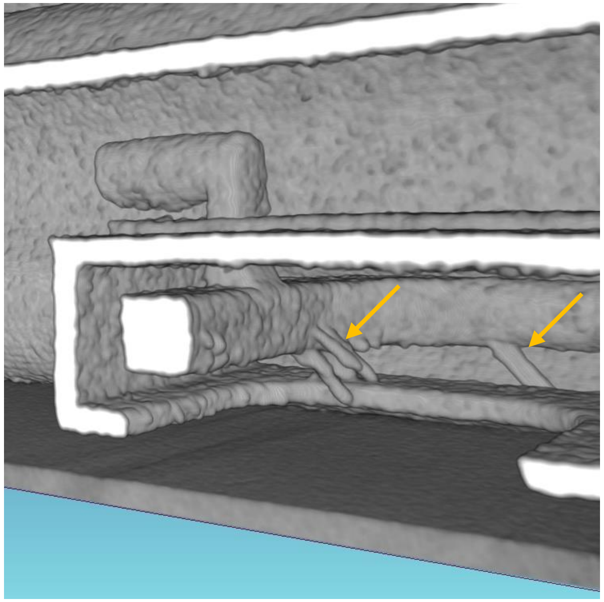
As-built HIP'ped

Non-destructive Evaluation (cont.)

1. Part inspection does not purely concern JPL at a microstructural level, but also macrostructural features in complex geomteries that are difficult to inspect
2. Additional concerns exist when considering multi-functional behaviors

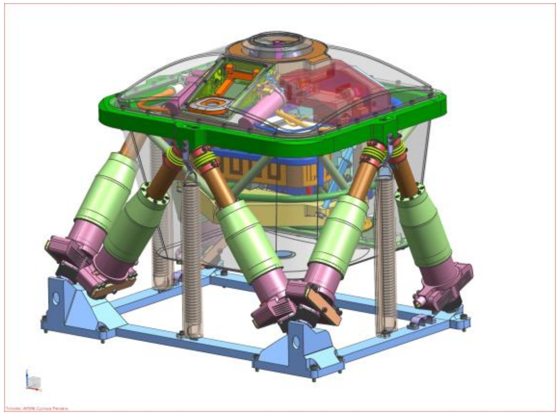




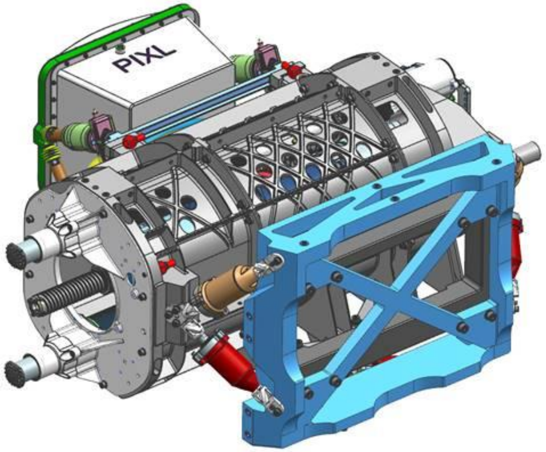


Insertion Opportunities

- PIXL is a non-structural part
  - Only requirements are to sustain its own mass and that of limited connectors
  - Fatigue and load insensitive
  - Purely needed for dust and cleanliness requirements
- Justification
  - Significant schedule and cost reduction from conventional processes
  - Allows for unique tailoring of geometry to improve form/fit requirements
- Requirements for flight
  - Test coupons built with the development and flight hardware must be evaluated at worst conditions (Worst Case Hot, maximum expected load)
  - Proof testing for entire structure



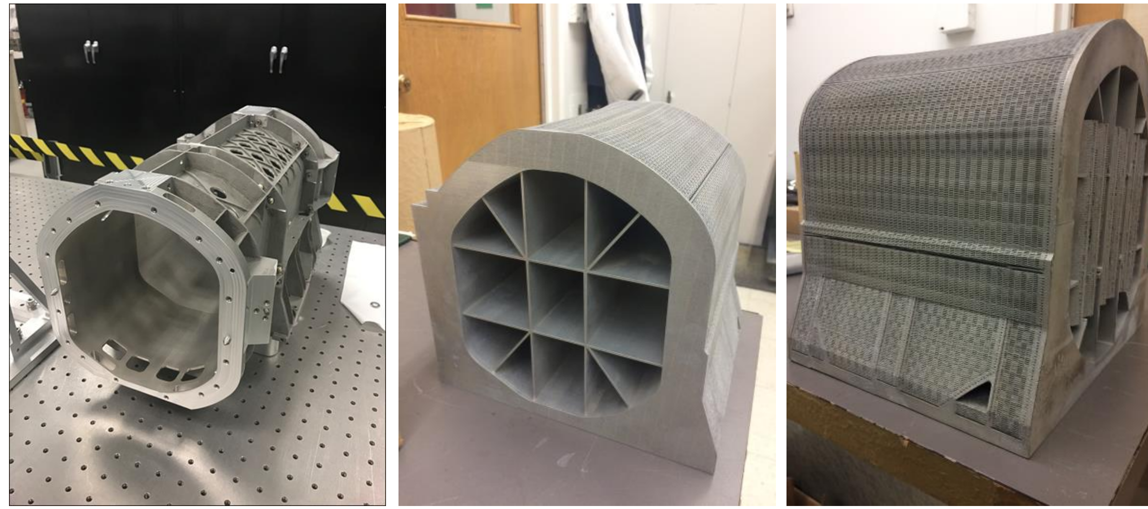
Planetary Instrument for X-ray Lithochemistry (PIXL), Mars 2020 (Image JPL/NASA)



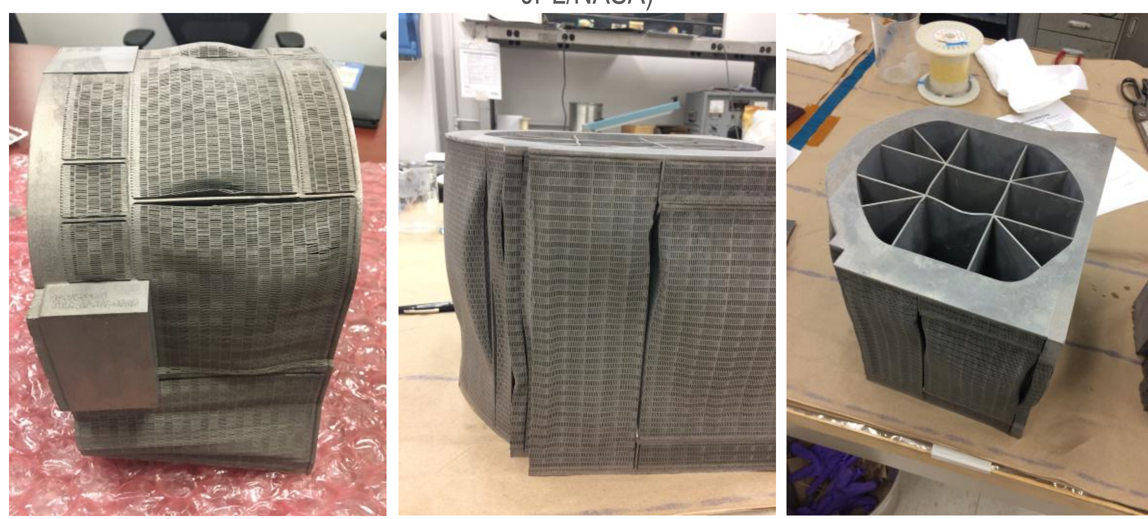
PIXL and Coring Drill, Mars 2020 (Image JPL/NASA)

Insertion Opportunities

- Coring Drill Chassis (Mars 2020)
  - Development unit only (not for flight)
  - Flight hardware will be machined from single billet
  - Built as 3 pieces, machined and bolted together
- Justification
  - Significant schedule and cost reduction from conventional processes
  - Provided significant increase in testing time, due to reduced production schedule
- Challenges
  - Significant size and residual stresses from quenching
  - Proof testing for entire structure



Development Coring Drill, Mars 2020 (Image JPL/NASA)



Conclusions

1. **Organic development** of mechanical properties based upon program need.
    1. Require all projects to build standard geometry specimens and perform limited testing.
    2. Aim for common property needs (e.g. thermal conductivity, stress vs. strain, etc.)
2. **Limited** introduction at current time.
    1. Quantify vendor-to-vendor variability (in work)
    2. Aggressive proof-testing and mechanical evaluation at critical design points
3. Process improvement
    1. Advanced HIP'ping technology leading to single-run HIP'ping, stress relief and aging
    2. Understanding evolution in powder sourcing, cleanliness, etc.
4. Materials & Processes focused on informed decisions for AM insertion onto flight programs.
    1. Avoiding improper usage (e.g. flat plate)
    2. Understanding complete process flow for post-build challenges (e.g. joining, surface finish, etc.)
    3. Understand nature of desired component

Acknowledgements

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